Fifth Annual Conference on Carbon Capture & Sequestration

Steps Toward Deployment

Geologic Storage - Modeling

CO_2 STORAGE CAPACITY IN DEPLETED AND NEAR-DEPLETED U.S. OIL RESERVOIRS

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OUTLINE FOR DISCUSSION

1. Attributes of Oil Reservoirs
2. An Initial Perspective of CO_2 Storage Capacity and CO_2-EOR Potential
3. Expanding CO_2 Storage
4. Revised Estimates of Usable CO_2 Storage Capacity
5. Summary

ATTRIBUTES OF OIL RESERVOIRS

Existing depleted and near-depleted oil reservoirs have numerous attributes that make them preferred sites for geological storage of CO_2.

1. ***Established Secure Trap.*** An oil reservoir has accumulated and held fluids for millions of years, thus providing:
    - Confidence in the integrity of the reservoir seal
    - Assurance of permanence of the fluid trap

As such, CO_2 injected into an oil reservoir, as long as the injected CO_2 volumes do not exceed the spill point, will likely remain "permanently" trapped and stored.

ATTRIBUTES OF OIL RESERVOIRS (Cont'd)

2. Value-Added Products. In geologically favorable settings, injecting CO_2 into a near-depleted oil reservoir can mobilize and recover significant volumes of additional oil using enhanced oil recovery technology (EOR):

- Recent work by Advanced Resources International for U.S. DOE's Office of Oil and Natural Gas shows that nearly 89 billion barrels of additional oil may be technically recoverable using CO_2 enhanced oil recovery (CO_2-EOR). Advanced ("next generation") technologies would add to this total.
- This would provide revenues for offsetting some (or all) of the costs of storing CO_2.
- The U.S. and many other parts of the world have large, mature oil fields with reservoir properties favorable for combining storage of CO_2 with CO_2-EOR.

ATTRIBUTES OF OIL RESERVOIRS (Cont'd)

3. <u>Existing Infrastructure.</u> In many cases, much of the essential requirements and infrastructure (such as wells, surface facilities, land access, mineral rights) already exists for storing CO_2. As such:

- The initial capital requirements for establishing a CO_2 storage facility would be lower than with an alternative option.
- The permitting, land disturbance and public acceptance aspects of CO_2 storage would be more favorable in areas already developed and comfortable with injection of fluids into the subsurface.

ATTRIBUTES OF OIL RESERVOIRS (Cont'd)

While depleted oil fields are an attractive, early option for CO_2 storage, particularly with CO_2-EOR, the perception is these oil fields offer a relatively small volume of CO_2 storage capacity as stated in the IPCC Special Report on Carbon Dioxide Capture and Storage:

> *"Enhanced oil recovery operations have the lowest capacity of all forms of CO_2 geologic storage, estimated globally at 61 to 123 billion tons of CO_2"*

> *" . . . it is important to note that CO_2 EOR, as practiced today, is not engineered to maximize CO_2 storage. In fact, it is optimized to maximize revenues from oil production, which in many cases requires minimizing the amount of CO_2 retained in the reservoir. In the future, if storing CO_2 has an economic value, co-optimizing CO_2 storage and EOR may increase capacity estimates."*

AN INITIAL PERSPECTIVE OF CO_2 STORAGE CAPACITY AND CO_2-EOR POTENTIAL

Given the perception that depleted oil reservoirs offer only limited capacity for storing CO_2, the presentation addresses two key issues:

1. *How might one establish a reliable assessment of CO_2 storage capacity with "value-added" oil production using today's enhanced oil recovery technology?*
2. *What opportunities might a "next generation" set of technologies offer for maximizing the CO_2 storage capacity (and oil recovery) in these oil reservoirs?*

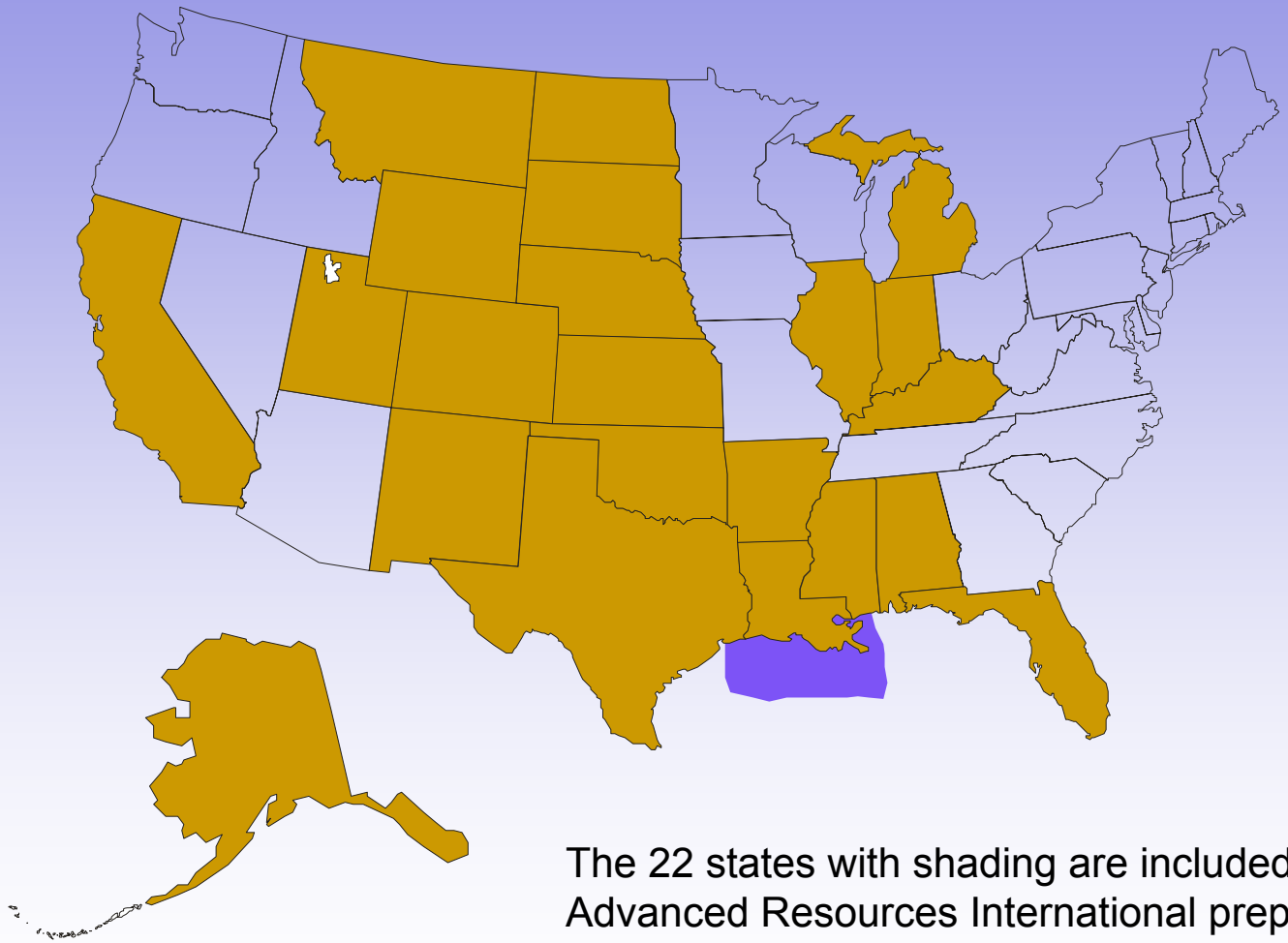
AN INITIAL PERSPECTIVE OF CO_2 STORAGE CAPACITY AND CO_2-EOR POTENTIAL (Cont'd)

Our company, Advanced Resources International, recently completed a series of ten "basin studies" that provide an initial perspective on the CO_2 storage potential from combining CO_2 storage and CO_2-EOR. The studies:

- Cover 22 of the oil producing states plus offshore Louisiana,
- Include 1,581 large (>50 MMBbls OOIP) oil reservoirs, accounting for two thirds of U.S. oil production,
- Estimated CO_2 storage capacity using a streamline reservoir simulation and an extensive data base of reservoir properties.

These reports are available on the U.S. Department of Energy's web site at http://www.fe.doe.gov/programs/oilgas/eor/Ten_Basin-Oriented_CO2-EOR_Assessments.html

U.S. BASINS/REGIONS STUDIED FOR FUTURE OIL RECOVERY AND CO_2 SEQUESTRATION POTENTIAL FROM CO_2-EOR



The 22 states with shading are included in the ten Advanced Resources International prepared 'basin studies" of CO_2-EOR and CO_2 sequestration.

AN INITIAL PERSPECTIVE OF CO_2 STORAGE CAPACITY AND CO_2-EOR POTENTIAL (Cont'd)

The market for "EOR-Ready" CO_2 is on the order of 20 billion metric tons of CO_2. About 80% of this would become stored as part of CO_2-EOR. Since currently known natural CO_2 sources hold only about 2 billion metric tons, CO_2-EOR offers a major market for industrial CO_2.

	Recoverable Oil	Purchased CO_2		Stored CO_2
	(Billion Barrels)	(Tcf)	(Billion Tonnes)	(Billion Tonnes)
Technically Recoverable	89	377	20	16
Economically Recoverable				
• Mod Oil Price/High Cost CO_2 *	23	85	4	3
• High Oil Price/Low Cost CO_2 **	47	188	10	8

* $30 per bbl oil price, CO_2 cost of $1.50/Mcf, ROR of 15% before tax.

** $40 per bbl oil price, CO_2 cost of $0.80/Mcf, ROR of 15% before tax.

USABLE CO_2 STORAGE CAPACITY IN OIL FIELDS FAVORABLE FOR CO_2-EOR ("State-of-the-Art" CO_2-EOR)

The usable CO_2 capacity for oilfields favorable for CO_2-EOR (under "state-of-the-art" CO_2-EOR technology) is provided below by basin/area:

Basin/Area	Usable CO_2 Storage Capacity	
	(Tcf)	(million tonnes)
Alaska	42.1	2,226
California	19.7	1,042
Gulf Coast	27.6	1,458
Louisiana (Offshore)	23.5	1,243
Mid-Continent	29.8	1,574
Illinois and Michigan	4.6	243
Permian	78.1	4,126
Rocky Mountain	22.5	1,192
East and Central Texas	50.8	2,688
Williston	10.1	532
TOTAL	308.9	16,325

EXPANDING CO_2 STORAGE

The volumes of CO_2 purchased for (and stored by) CO_2-EOR, as set forth in the ten "basin studies" assume:

- The primary objective is enhancing economic oil recovery (minimizing costs while optimizing oil production).
- No economic value or benefit is placed on "permanently" storing CO_2.

As such, the above CO_2 requirements and storage volumes represent a minimum. The remainder of the paper examines how and by how much this minimum volume could be expanded.

EXPANDING CO_2 STORAGE: A CASE STUDY

To examine the potential for expanding CO_2 storage in depleted oil fields, we use a case study of a large, 340 million barrel (OOIP) Gulf Coast oil reservoir. It has a main pay zone (above the producing oil-water contact), an underlying transition/residual oil zone, and a strong bottom water aquifer.

This reservoir offers 2,710 Bcf (143 million tonnes) of theoretical CO_2 storage capacity.

- Main Pay Zone:
  - Depth - - 14,000 feet
  - Porosity - - 29%
  - Net Pay - - 325 feet
  - Initial Pressure - - 6,620 psi
- Transition/Residual Oil Zone (130 feet)
- Underlying Saline Aquifer (195 feet*)

*Within the spill point of the reservoir structure.

EXPANDING CO_2 STORAGE: A CASE STUDY (Cont'd)

First, this Gulf Coast oil reservoir is produced using "state-of-the-art" CO_2-EOR project design, targeting the main pay zone (MPZ), with vertical wells, and injecting 1 HCPV of CO_2 with a 1:1 WAG (including both purchased and recycled CO_2).

The CO_2 storage and oil recovery results from this CO_2-EOR design are as follows:

- CO_2 Purchased - - 424 Bcf (22.4 million tonnes)
- Oil Recovery - - 64 million barrels
- CO_2/Oil Ratio - - 6.6
- CO_2 Stored* - - 350 Bcf (18.6 million tonnes)

**CO2 storage is 82% of purchased CO_2.*

Under this design, only about 13% of the theoretical storage capacity (available pore space) in the reservoir is used for CO_2 storage.

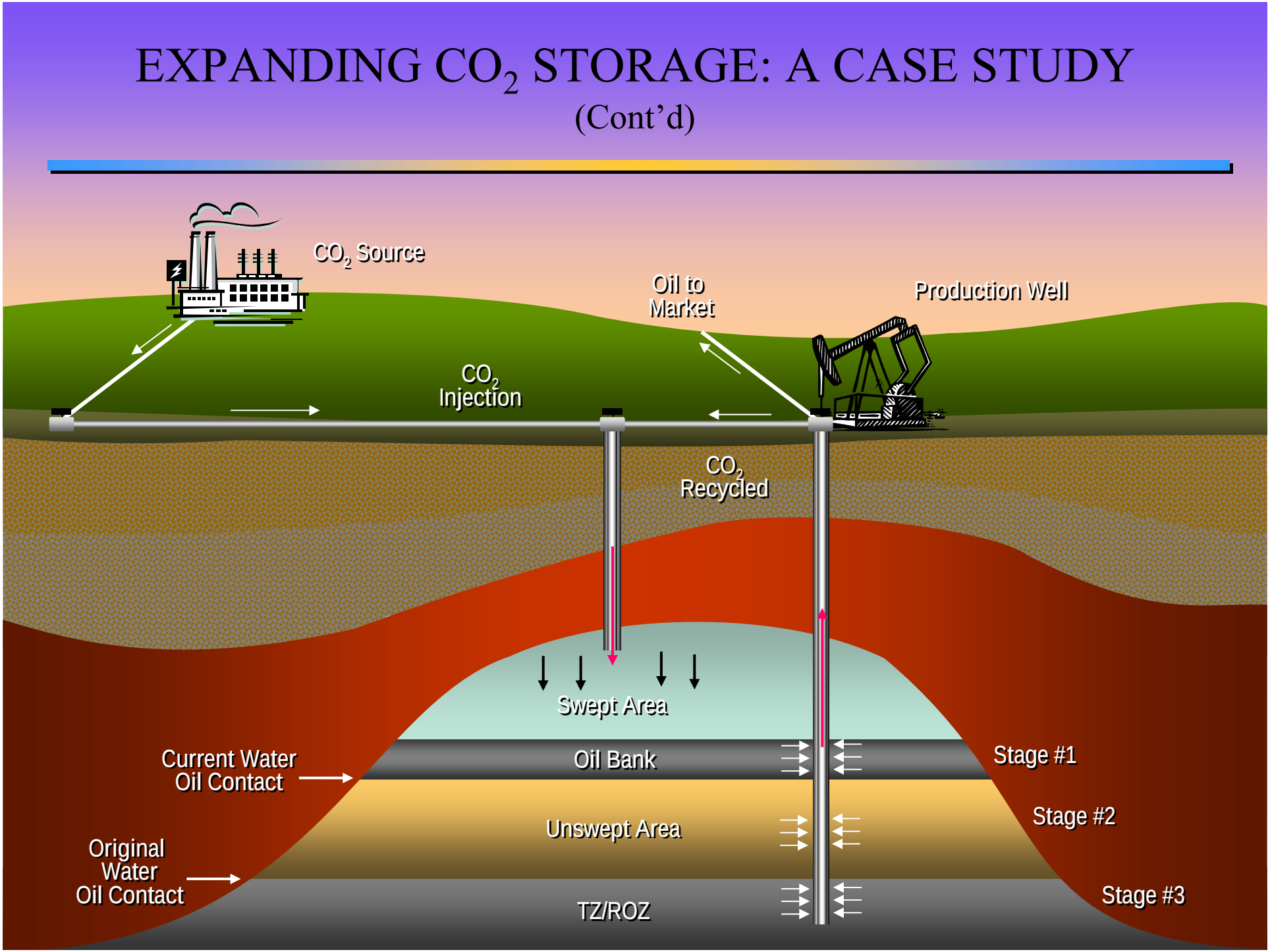
EXPANDING CO_2 STORAGE: A CASE STUDY (Cont'd)

Next, this Gulf Coast oil reservoir is produced using "next generation" CO_2-storage and CO_2-EOR project design. This alternative design includes:

- Conducting a gravity-stable, vertical CO_2 injection with horizontal wells.
- Targeting the main pay zone plus the transition/residual oil zone and the underlying saline aquifer.
- Injecting continuous CO_2 (no water)
- Continuing to inject CO_2 after completion of oil recovery, until maximum allowed reservoir pressure is reached.

EXPANDING CO_2 STORAGE: A CASE STUDY

(Cont'd)



EXPANDING CO_2 STORAGE: A CASE STUDY
(Cont'd)

Considerably more CO_2 storage is possible in this reservoir with "next generation" CO_2-EOR and storage design. An added bonus is that oil recovery is also increased.

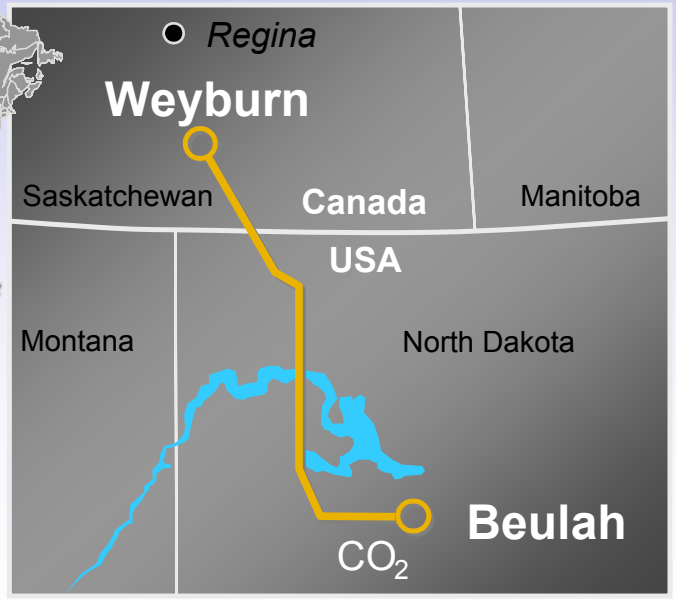
	MPZ	TZ/ROZ	Aquifer	TOTAL
CO_2 Stored (Bcf)				
• Bcf	1,150	410	500	2,060
• Million Tonnes	61	22	26	109
Oil Recovery (million barrels)	112	68	--	180

Under this scenario, 76% (instead of 13%) of the reservoir's theoretical storage capacity is used for CO_2 storage.

Oil recovery is 180 million (instead of 64 million) barrels, providing an additional 116 million barrels.

Weyburn Enhanced Oil Recovery Project

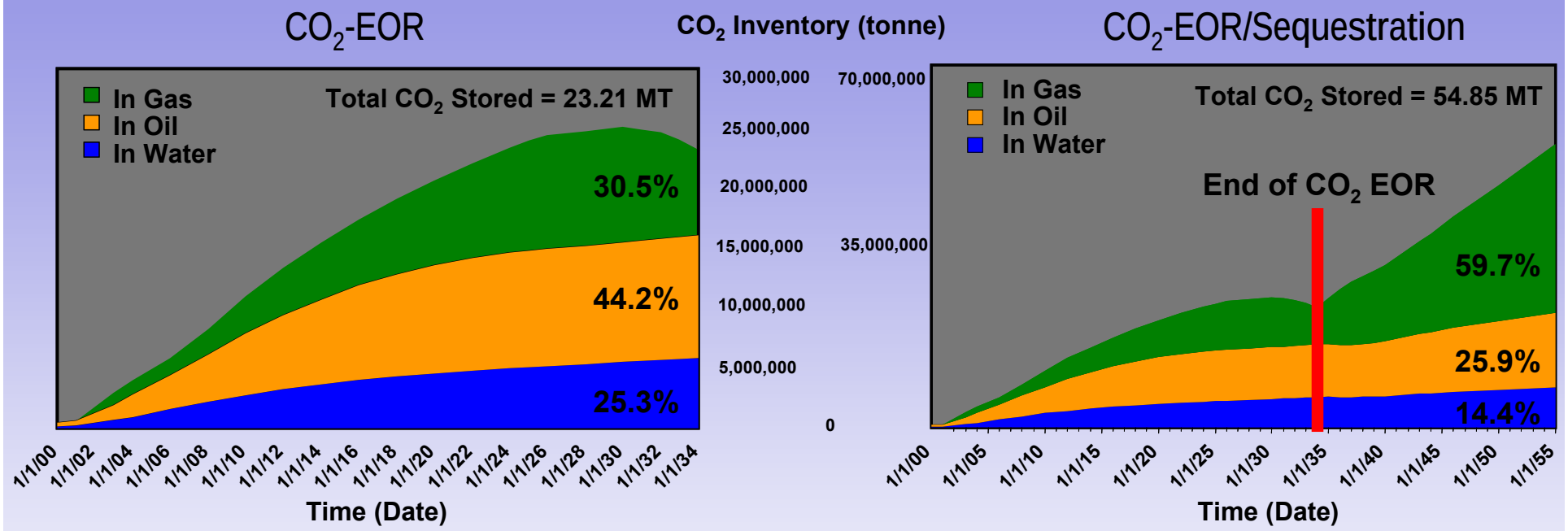
(An Operating Project Maximizing Oil Recovery and CO_2 Storage)

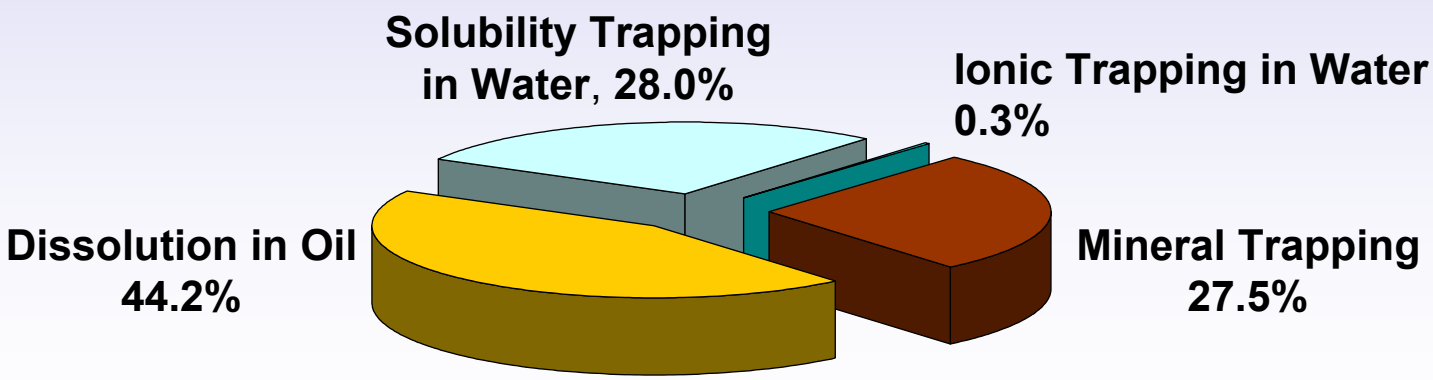


The Weyburn Advantage

- Largest CO_2 EOR project in Canada:
  - OOIP 1.4 Bbbls
  - 155 Mbbls incremental
- Outstanding EOR response
- World's largest geological sequestration project
  - 2.4 MMt/year (current)
  - 7 MMt to date
  - 23 MMt with EOR
  - 55 MMt with EOR/sequestration

CO_2 Storage Capacity and Distribution Predictions and the Application of Economic Limits





REVISED ESTIMATES OF USABLE CO_2 STORAGE CAPACITY

The insights gained from the case study and the Weyburn experience are used to provide a revised estimate of CO_2 storage capacity in depleted domestic oil reservoirs.

The revised estimate assumes that: (1) "next generation" CO_2-EOR technology is employed (in reservoirs favorable for this technology) and (2) that storing CO_2 becomes an equal objective with recovering oil. Under these two assumptions, the revised CO_2 storage capacity in depleted domestic oil fields is as follows:

- Oil fields favorable for CO_2-EOR: 52 billion metric tons
- Other oil fields (not favorable for CO_2-EOR): 23 billion metric tons*
- Total U.S. CO_2 storage capacity in depleted oil fields: 75 billion metric tons

*Estimated by extrapolation from studied oil fields.

USABLE CO_2 STORAGE CAPACITY IN OIL FIELDS FAVORABLE FOR CO_2-EOR

("Next Generation" CO_2-EOR/CO_2 Storage Technology)

The CO_2 storage capacity in oil fields favorable for CO_2-EOR ("next generation" CO_2-EOR technology that optimizes oil recovery and CO_2 storage), is provided below by basin/area:

Basin/Area	Usable CO_2 Storage Capacity		Theoretical Capacity	
	(Tcf)	(million tonnes)	(Tcf)	(million tonnes)
Alaska	133.7	7,064	310.3	16,398
California	68.2	3,603	134.1	7,087
Gulf Coast	88.4	4,672	155.3	8,211
Louisiana (Offshore)	81.0	4,282	142.9	7,554
Mid-Continent	94.4	4,991	222.2	11,747
Illinois and Michigan	17.6	931	27.0	1,429
Permian	248.2	13,119	355.4	18,784
Rocky Mountains	62.3	3,291	91.3	4,828
East and Central Texas	168.5	8,904	306.9	16,219
Williston	27.9	1,476	43.4	2,293
TOTAL	990.1	52,332	1,788.9	94,549

COMPARISON OF USABLE AND THEORETICAL CO_2 STORAGE CAPACITY

Under "state-of-the art" CO_2–EOR, where oil recovery is the primary objective, only 17% of the overall theoretical storage capacity offered by depleted U.S. oil fields is used, consistent with the case study.

With application of "next generation" CO_2-EOR technology, that combines both CO_2-EOR and CO_2 storage, a much higher percentage, 55%, of the overall theoretical storage capacity is used:

- Theoretical Storage Capacity: 95 billion metric tons
- Useable CO_2 Storage Capacity:
  - "State-of-the-Art":16 billion metric tons (17% theoretical)
  - "Next Generation": 52 billion metric tons (55% theoretical)

SUMMARY

Depleted oil reservoirs have attributes that make them attractive for storing CO_2 - - secure trap; "value-added" products; and, existing infrastructure.

Using today's "state-of-the-art" CO_2-EOR only a small portion of the available CO_2 storage capacity in the oil reservoir is productively used, 16 G mt.

Applying "next generation" practices that integrate the storage of CO_2 and oil recovery, a much greater portion of the available CO_2 storage capacity becomes useable, 52 G mt.

Including oil fields, not favorable for CO_2-EOR, the total U.S. CO_2 storage capacity in depleted onshore/near-off shore oil reservoirs becomes 75 G mt.

New field discoveries and inclusion of deepwater reservoirs would add to this total.

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